used the maximum kelp area as the best indicator of rocky reef because giant kelp typically does not cover all rocky substrates, so the use of data from other years would lead to a gross underestimate of rocky reef area. Aerial photographs taken by CDF&G were digitized with AutoCad Version 10 and areas of each coastal section were determined with Surfer Version 7.

The areas are given in Table 9. Segment 3 had the largest area of giant kelp (144 ha), followed by segment 4 with 95 ha and segment 7 with 68 ha. The total area of giant kelp along the Palos Verdes Peninsula was 459 ha.

Table 9. Shallow reef areas for the coastal segments in the Palos Verdes region. Areas based on maximum surface canopy of giant kelp (1989).

	Coastal segment							
	3	4	4.5	5	6	7	8	9
Reef area (ha)	144	95	40	17	20	68	41	33

3.2.2.6. Standing stocks for rocky reef fish

Standing stocks of kelp bass and black surfperch were calculated by multiplying the biomass density (kg/ha) for each coastal segment by the area (ha) of rocky reef in that segment.

Because no surveys were taken in segments 8, 9 and 10, biomass densities for these segments had to first be estimated before standing stocks could be calculated. Biomass densities for these segments were estimated as the average of the biomass densities in the four survey locations in the Palos Verdes region (Palos Verdes Point, Abalone Cove, Bunker Point, and KOU Reef).

Standing stock estimates are given in Table 3 and Table 4

3.3. Estimates of biomass exceeding thresholds

To estimate the biomass exceeding thresholds, the standing stocks were multiplied by exceedances. This approach assumes that the injury from DDT contamination is limited to exceedances and that DDT does not have an effect on standing stock.

For each species and each time period, the average standing stock for each segment was multiplied by the exceedance value for that period and segment to calculate the average standing stock exceeding a threshold in that segment and time period. The average standing stock of each species and time period for the entire Palos Verdes region was calculated by summing the sections.

For example, for Dover sole in 1981-86, the average standing stock in segment 3 (18,981 kg) is multiplied by the exceedance value for 1981-86 (0.00) to get a biomass exceedance of 0 kg for that segment. In segment 9, the standing stock (2,081 kg) is multiplied by the exceedance (0.75) to get a biomass exceedance of 1,561 kg for that segment. The sum of the biomass exceedance for Dover sole in all segments for 1981-86 is 7,500 kg. This procedure was also followed for 1987-91 and 1992-99.

To calculate the overall yearly standing stock exceeding thresholds, the values for the four target species are summed. This information provides the target for primary restoration as well as the inputs to the Resource Equivalency Analysis, which is used to calculate the target for compensatory restoration.

Estimates for white croaker are given in Table 1, for Dover sole in Table 2, for kelp bass in Table 3, and for black surfperch in Table 4. Table 10 presents a summary of biomass losses. For 1981-86, the yearly standing stock exceeding the threshold (5 ppm) was 24,421 kg. For 1987-91, the yearly standing stock exceeding the threshold (5 ppm) was 13,982 kg. For 1992-99, the yearly standing stock exceeding the threshold (0.1 ppm) was 47,414 kg.

Table 10. Summary of biomass exceeding thresholds.
The threshold for 1981-86 and 1987-91 is 5 ppm; the threshold for 1992-99 is 0.1 ppm.

	Yearly Biomass exceeding thresholds (kg)		
	1981-86	1987-91	1992-99
White croaker	13,939	12,200	11,623
Dover sole	7,500	1,751	11,595
Kelp bass	2,981	31	18,700
Black surfperch	0	0	5,496
YEARLY TOTAL	24,421	13,982	47,414

4.0 Artificial reefs

The suitability of artificial reefs as restoration for fish injuries has been evaluated in Ambrose (1994). Artificial reefs are appropriate as restoration for fish injuries because they will provide clean fish to replace or compensate for damages. By placing the artificial reefs in areas with low sediment concentrations of DDT, the fish that occur on the reef will be "clean" (i.e., have muscle concentrations below the California State trigger level of 0.1 ppm). In this section, I discuss some of the design issues related to using artificial reefs as restoration for injuries to fish sought by anglers, particularly as they relate to determining the size and cost of an appropriate restoration project.

4.1. Fish on artificial reefs

Throughout the world, fish are consistently associated with artificial reefs. Although there is controversy over the degree to which artificial reefs enhance the *production* of fish (Bohnsack and Sutherland 1985), there is no doubt that most artificial reefs support a substantial standing stock of fish. Whether or not artificial reefs produce or primarily attract fish, the standing stock of clean fish on artificial reefs could be used as compensation for the standing stock of fish that exceeds FDA action levels or the California State trigger levels.

4.1.1. Biomass density of fish on artificial reefs

Relatively few studies have estimated the biomass density (kg/ha) of fish on artificial reefs in southern California. In this section, I summarize data available for artificial and natural reefs in southern California. My familiarity with the data summarized here varies. I was directly involved in estimates from Ambrose (1987), Barnett et al. (1991), and Beers (unpublished), and modeled my methodology after DeMartini (DeMartini et al. 1989, Larson and Demartini 1984; DeMartini was also involved with Barnett et al. 1991), so I am most familiar with basis for those estimates. Quast (1968) published the methodology he used for his estimates. Although Stephens has published his survey methodology (Stephens and Zerba 1981, Stephens et al. 1984), I have not had an opportunity to review his methods for biomass density calculations.

The results of these studies are summarized in Table 11. For information purposes, I present total biomass density of all species. The calculation of gains to compensate for injuries due to DDT contamination considers only the biomass of sport fish because these are the species to which FDA action levels and California State trigger levels would apply. Thus, the species considered for the estimates of both injuries and restoration are species to which FDA action levels and California State trigger levels would apply. Biomass density of sport fish ranged from 72 to 1,574 kg/ha, with an average of 270 ± 399 kg/ha (Mean ± SD). These data were collected using different methods and over different time periods. Ambrose (1987; also in Ambrose and Swarbrick 1989) reported biomass based on a single survey per reef, but with all surveys conducted during a single period of time. Stephens (unpublished data) summarized surveys conducted over 20 years on one reef, the King Harbor Breakwater. Barnett et al. (1991; see also Johnson et al. 1994 and DeMartini et al. 1994) conducted surveys at one of the reefs surveyed by Ambrose, Torrey Pines Artificial Reef, over a 7-month period of time. Biomass was estimated by a number of different methods for different species, including visual transects and mark-recapture.

Different species of fish were included in the different estimates summarized. Some differences are due to different methodologies, including the height of visual transects. Barnett et al. (1991) only include some fish in their estimates; estimates for sport fish include only kelp bass, black perch, barred sand bass, and sheephead. In addition, DeMartini et al. (1989) include transients in their estimate, and Stephens (unpublished) also includes some transients and other species not included in the other estimates.

In addition to different methods and time periods, the types of reefs surveyed differed. Two reefs were concrete, one with a relatively high biomass density of sportfish and one with a low biomass density. Four of the reefs were "emergent" (i.e., the substrate extended above the water), including the King Harbor Breakwater studied by

Stephens. Four of the reefs were the traditional "rockpile" reefs, formed from piles of quarry rock placed on the bottom.

Stephens' estimates for the King Harbor breakwater are considerably higher than the other estimates. Stephens' estimates are based on an average of 20 years' of data, a much longer time period than the other studies, but the estimates are consistently higher regardless of the time period used. Without his estimate, biomass density of sport fish is 161 ± 79 kg/ha, nearly 100 kg/ha lower.

Table 11. Biomass density (kg/ha) of fish on artificial reefs in southern California. NR=not reported.

Reef	Size (ha)	Biomass (kg/ha)		Comments	Source
		All species	Sport fish		
Torrey Pines AR	0.18	665	80		Ambrose 1987, Ambrose and Swarbrick 1989
Pendleton AR	1.40	359	115		
Newport Beach AR	2.50	783	278	concrete	
LA Harbor Breakwater (inside)	5.81	525	193	emergent	
LA Harbor Breakwater (outside)	4.75	495	213	emergent	
King Harbor Breakwater	3.86	251	101	emergent	
Hermosa Beach AR	0.24	252	79	concrete	
Marina del Rey AR	0.32	481	168		
Pitas Point AR	0.45	632	280		
	2.81	251	72	emergent	
Pendleton AR	1.3	398	243	includes transients	DeMartini et al. 1989
King Harbor Breakwater	NR	2,663	1,574	emergent; avg. of 20 years	Stephens (unpublished)
Torrey Pines AR		217	109	not all species	Barnett et al. 1991
		613 ± 641	270 ± 399		

Data on biomass densities on natural reefs may also provide an indication of the likely standing stock of fish that will develop on an artificial reef. In some ways, natural reef biomass density might be a better predictor of standing stock on a large artificial reef because existing artificial reefs are relatively small and may exhibit more edge effects (Ambrose and Swarbrick 1989). Therefore, I have summarized information on biomass density on natural reefs in southern California in Table 12.

Temperate and tropical reef biomass is usually in the range of a few to several hundred kg/ha (Larson and DeMartini 1984), and this is consistent with biomasses reported by Ambrose (1987), Larson and DeMartini (1984), and Quast (1968). The biomass density reported by Stephens (unpublished, but some years previously reported in Stephens and Zerba [1981] and Stephens et al. [1984]) is much higher, several thousand kg/ha for all species and more than one thousand kg/ha for sport fish. Beers' data include only three sport species, kelp bass, barred sand bass (*Paralabrax nebulifer*), and sheephead (*Semicossyphus pulcher*). Also, half of the reefs sampled by Beers were in no-take protected areas, so the standing stocks could be expected to be higher than they would be at the other sites surveyed, which were all open to fishing. Overall, the biomass density of sport fish was 239 ± 235 kg/ha, a bit higher than the estimate for densities on artificial reefs. Without Stephens' estimate for Palos Verdes Point, the estimate is 206 ± 136 kg/ha.

Table 12. Biomass density of fish on natural reefs in southern California.
NR=not reported. Beers (unpublished data) included only kelp bass, barred sand bass and sheephead.

Reef	Size (ha)	Biomass (kg/ha)		Comments	Source
		All species	Sport fish		
Marine Street Reef	220	148	41		Ambrose 1987
La Jolla Cove Reef		289	78		
	214	175	72		
	80	164	53		
Las Pulgas Reef	53	154	35		
Box Canyon	16	130	52		
San Onofre Kelp – Main	104	348	220		
San Onofre Kelp – North		420	190		
San Mateo Kelp	114	430	211		
Two Man Rock		797	303		
	23	352	157		
	31	426	112		
	551	495	115		
		1,037	390		
		90	13		
	6.8	331	146		
	NR		433	in no-take zone	Beers (unpublished)
	NR		275	in no-take zone	
	NR		195	in no-take zone	
d – Natural Area	NR		312	in no-take zone	
i – Pelican Closure	NR		339	in no-take zone	
	NR		63		
	NR		287		
	NR		381		
Anacapa Island – Natural Area	NR		395		
Anacapa Island – Pelican Closure	NR		219		
Palos Verdes Point	NR	3,280	1,319		Stephens (unpublished)
San Onofre Kelp	87.9	442	244	incl. transients	DeMartini et al. 1989
San Onofre Kelp	NR	389	264	SOK-U	Larson and DeMartini 1984
		653	548	SOK-D	
		243	236	cobble	
Bathtub Reef	NR	102	45	excl barracuda	Quast 1968
	NR	204	156		
		483 ± 652	239 ± 235		

Arguably, the data for artificial reefs should be used to estimate the biomass density that would occur on an artificial reef constructed as restoration for damages due to DDT in fish tissues. However, there is little reason to expect fish biomass densities on large artificial reefs to be different from biomass densities on natural reefs (but see Ambrose and Swarbrick [1989] for a discussion of why biomass densities might differ on small artificial reefs). Moreover, there is no obvious difference in estimates for artificial and natural reefs given in Table 11 and Table 12. Therefore, I use the average of all biomass density estimates, 248 kg/ha (SD=286), as the estimate for biomass density on the restoration reef.

Although there is no obvious difference in estimates for artificial and natural reefs, John Stephens' estimates of biomass density are noticeably higher than the other estimates made for southern California reefs. Although Stephens provides only two values, they are so much higher than the other estimates that they strongly influence the overall average. The average of all biomass densities except Stephens' might provide a better estimate of the biomass density likely to occur on a restoration reef. The Mean ± SD of all biomass densities except Stephens' is 193 ± 124 kg/ha.

4.1.2. Development of fish biota on artificial reefs

The biomass densities reported for artificial reefs in Table 11 were for reefs of varying ages, from several years old (Pitas Point AR) to about 100 years old (Los Angeles Harbor Breakwater). The pattern of development of fish standing stock on an artificial reef is important for calculating the restoration value of the reef. A number of studies, both in California and elsewhere, have shown that fish are quickly attracted to a new artificial reef, and that a substantial standing stock develops in a short period after a reef is constructed.

The development of the fish assemblage on an artificial reef has been studied closely for Pendelton Artificial Reef (PAR) in northern San Diego County. Ambrose and Anderson (1989) summarized the studies by several different groups on PAR. Fish appeared immediately after reef construction and colonization by species occurred rapidly over time. Four species (kelp bass, barred sand bass, black surfperch, and white seaperch) were observed one day after construction. Eleven additional species (California halibut, sculpin, blacksmith, garibaldi, California sheephead, pile surfperch, halfmoon, opaleye, giant sea bass, sargo, and rock wrasse) were noted three months later. After construction in 1980, there was a fairly steady increase in number of species that had been recorded on the reef until 1984, when the cumulative number of fish species reached 45 species; it remained at 45 species until the end of sampling in 1987. Total fish density at PAR increased greatly in 1984, after blacksmith recruited to PAR, but was fairly constant thereafter. There were notable changes in populations in the bottom/slope microhabitat after 1984, with some species (black surfperch, halfmoon and kelp bass) declining and others (California sheephead and rock wrasse) increasing; total fish minus blacksmith also declined in the bottom/slope habitat after 1984.

The data from PAR suggest that fish respond quickly to the presence of an artificial reef, and that within approximately 4 years a reasonably mature and stable fish assemblage had developed. The extent to which this experience can be expected at other artificial reefs is not clear. Other factors influencing fish and operating at PAR may not follow this same time course. For example, *Cryptoarachnidium argilla*, an encrusting ectoproct that seemed to delay the development of benthic organisms at PAR, maintain high cover until 1983 and then dropped to low abundances. This coincided with the colonization of the final fish species found at PAR and the recruitment of blacksmith, but it is not known if there was a cause-effect relationship. However, *Cryptoarachnidium* has persisted for longer than 3 years at other reefs, including artificial reefs built in Santa Monica Bay (D. Bedford, *personal communication*), so it is possible that the fish assemblage might not develop as quickly at other sites. On the other hand, it is possible that the fish assemblage might develop more quickly at some sites, although I know of no data indicating this.

PAR, like most rock pile reefs in southern California, is fairly small, only 1.4 ha. It seems likely that such a small reef could quickly develop a high standing stock by attracting enough fish from nearby areas to "fill" the reef. On the other hand, a very large artificial reef might take much longer to acquire a large standing stock because the number of reef fish in nearby areas would not be enough to "fill" the reef. Instead, the standing stock on a very large artificial reef may not fully develop until the fish recruiting to the reef survive and grow, which could take several years.

On balance, I consider four years to be a reasonable estimate of the length of time required for the fish standing stock to develop on an artificial reef. There is uncertainty about this estimate, but I think it is more likely to be longer than shorter on the large reef(s) that would be constructed in this case.

4.2. Designs

Artificial reefs have been constructed using many different designs. In California, reefs have been built from natural rock, concrete, old cars and streetcars, tires, and decommissioned ships. Recently, there has also been discussion of using "rope reefs" to establish kelp beds. Early experiences with cars, streetcars and tires demonstrated problems with long-term stability and longevity, and decommissioned ships are generally used as a diving attraction rather than ecosystem enhancement.

In spite of the variety of artificial reef types, most reefs in California have been constructed of quarry rock and most studies of reef communities have been conducted on quarry rock reefs. The few studies of reefs constructed from concrete have indicated a range of results (Ambrose 1987, Patton *personal communication*). Some of the differences are undoubtedly due to differences in location and depth, as with quarry rock reefs. In addition, concrete reefs can vary tremendously in the nature of the substrate, which can vary from long columns to large flat slabs to small rubble, depending on the source material. Because little is known about how communities on concrete reefs would compare to communities on quarry rock reefs, the Southern California Edison Company, as part of its mitigation requirements for its operating permit from the California Coastal Commission, has constructed a large experimental reef off San Clemente, California. This experiment to compare these two substrates was begun in Fall 1999, and results are expected by 2005.

Even less is known about the benefits (and costs) of rope reefs designed to produce kelp beds. This technology has mainly been advocated by the Marine Forest

Society (http://www.webworldinc.com/unitedanglers-sc/MarineForestSociety.htm). Although there has been a demonstration project at Newport Beach, there is little information available about this technology, and no basis for determining the standing stock of fish that would be supported by a rope reef.

Because there is little quantitative information about fish standing stocks on concrete and rope reefs, in this report I consider primarily quarry rock reefs.

A second aspect of reef design is the configuration of material. Rocks (or other substrates) can be distributed in one group or in a number of separate groups (usually called modules). Rocks can be piled into a tall reef, or distributed in a single layer to make a short reef. Rocks can cover 100% of the substrate, or be distributed in a way that leaves open spaces amongst the rock. It is likely that these different configurations would result in differences in the fish assemblages on the reefs. Observations of existing artificial reefs, combined with knowledge of the natural history of reef fishes, suggest some patterns that might be expected. For example, it is likely that blacksmith will achieve high densities on high-profile (tall) artificial reefs. Arguments have also been made that kelp beds will be better sustained by low-relief reefs (Patton et al. 1994). Unfortunately, the information needed to predict quantitatively the standing stocks of different fish species on different reef configurations is lacking. Therefore, in this report I have synthesized information to provide a general prediction of fish standing stock on an artificial reef (Section 4.1.1), but I have not tried to make specific predictions for different configurations of artificial reefs.

4.3. Construction costs

The cost of constructing an artificial reef depends on many factors, including reef material, transport distance, reef design, and market forces. One way to estimate cost of building a new reef is to review the costs of reefs already built (The most recently constructed artificial reef is the San Clemente Reef, constructed by Southern California Edison as the experimental phase of a reef required by the California Coastal Commission as mitigation for impacts of the San Onofre Nuclear Generating Station. The quarry rock portion of this experimental reef cost $71/ton, which translated to $346,000 per ha. These costs might be somewhat inflated because of the very specific design requirements of the experiment, which required the precise placement of reef materials. In spite of this, it is somewhat below the overall average cost per ha of $419,000.

Table 13). The reefs described in the table were constructed between 1984 and 1999. Costs have not been adjusted for inflation. Reefs constructed in the 1980s had a cost of about $50/ton; reefs constructed more recently have cost about $70/ton.

The most recently constructed artificial reef is the San Clemente Reef, constructed by Southern California Edison as the experimental phase of a reef required by the California Coastal Commission as mitigation for impacts of the San Onofre Nuclear Generating Station. The quarry rock portion of this experimental reef cost $71/ton,

which translated to $346,000 per ha. These costs might be somewhat inflated because of the very specific design requirements of the experiment, which required the precise placement of reef materials. In spite of this, it is somewhat below the overall average cost per ha of $419,000.

Table 13. Construction costs of artificial reefs built in California by the California Depart. Fish and Game. Source: Dr. Hany Elwany, Coastal Environments, 29 March 2000.

Reef	Construction	Area Ha	Material	Tons	Modules	Cost Total	Cost per ton	Cost per ha
Pitas Point Reef	1984	0.4	Quarry Rock	7,200	4	$350,000	$48.61	$786,217
Topanga Canyon Reef	1987	0.8	Quarry Rock	10,000	2	$500,000	$50.00	$617,742
Santa Monica Bay Reef	1987	2.8	Quarry Rock	20,000	48	$1,000,000	$50.00	$352,995
Marine Del Rey Reef	1985	2.8	Quarry Rock	10,000	18	$500,000	$50.00	$179,056
Pendleton Reef	1980	1.3	Quarry Rock	10,000	8	$500,000	$50.00	$374,389
Oceanside Reef	1987		Quarry Rock	10,000	24	$500,000	$50.00	
Pacific Beach Reef	1987		Quarry Rock	10,000	24	$500,000	$50.00	
Morro Bay Reef			Quarry Rock	2,000	2	$150,000	$75.00	
Philips Reef	1999	0.7	Quarry Rock		*	$100,000		$145,351
San Clemente Reef	1999	4.5	Quarry Rock	22,000	28	$1,570,200	$71.37	$346,421
San Clemente Reef	1999	4.5	Concrete	14,500	28	$1,250,275	$86.23	$275,838
Averages		2		13,386		$810,068	$56.64	$418,951
* 1207 quarry rock boulders with upper surface area > 4 ft^2								

The Philips Reef, also constructed in 1999, had a very low cost of $145,000 per ha. However, this reef was constructed with a very different design from the other artificial reefs in California, and it is not clear that this design would be satisfactory for the restoration reefs.

Because it is difficult to predict the actual cost of an artificial reef without a better understanding for the reasons for the variation in costs in The most recently constructed artificial reef is the San Clemente Reef, constructed by Southern California Edison as the experimental phase of a reef required by the California Coastal Commission as mitigation for impacts of the San Onofre Nuclear Generating Station. The quarry rock portion of this experimental reef cost $71/ton, which translated to $346,000 per ha. These costs might be somewhat inflated because of the very specific design requirements of the experiment, which required the precise placement of reef materials. In spite of this, it is somewhat below the overall average cost per ha of $419,000.

Table 13 or details about the design of the restoration reefs, I use $419,000/ha as the best estimate of the cost of constructing a restoration reef. This estimate must be considered only a rough estimate, however.

5.0 Restoration

In this section, I consider two types of restoration: primary restoration and compensatory restoration. In most cases, primary restoration would remediate the contaminant problem so there would be no future injuries. Compensatory restoration would serve as compensation for the losses incurred because resources were injured in the past.

In the present case, as mentioned below, it will not be possible to provide primary restoration that will eliminate future injuries. An artificial reef is proposed to provide primary restoration by providing substitute clean fish resources that are equivalent to the injured resources. Thus, although there will still be contaminated fish in the Palos Verdes region, and these fish will not be available to fishermen, the artificial reef will provide an equivalent biomass of clean fish that *is* available to fishermen.

It is worth noting here that any type of artificial reef constructed as restoration for damages due to DDT contamination would increase the standing stock of reef fish where it is constructed – but it would also decrease the standing stock of soft-bottom fish in that area. The biomass density of fish on an artificial reef will be higher than the biomass density of fish in a soft-bottom habitat (Barnett et al. 1991), so there will still be a net increase if fish standing stock. However, the <u>net</u> standing stock of fish available because of the construction of an artificial reef will be less than the standing stock of reef fish on the reef. To account for the displacement of soft-bottom fish, the standing stock of fish attributed to the reef should be adjusted downwards. I have not made this adjustment, and the size of reef estimated to be necessary for restoration is smaller than it would be had this adjustment been made.

5.1. Primary restoration

Primary restoration in this case is designed to provide clean fish biomass equivalent to the standing stock that is now and will in the future exceed the California State trigger level of 0.1 ppm DDT.

Two scenarios are considered. First, I consider the standing stock that will exceed 0.1 ppm if a cap is placed over contaminated sediments and the cap is as effective as planned. Second, I consider the standing stock that will exceed 0.1 ppm if the contaminated sediments are not capped (or the cap is not effective). In both cases, I consider only white croaker and Dover sole. Although kelp bass and black surfperch may continue to exceed the State trigger levels in either scenario, there is insufficient information to project their exceedances into the future. If these two species do exceed the State trigger levels in the future, excluding them from this analysis will result in an underestimate of future injuries.

<u>5.1.1. Primary restoration in the presence of an effective sediment cap</u>

Information about the possible cap over contaminated sediments comes from analyses and documents produced by the U.S. Army Corps of Engineers Waterways